GOES

Advanced Baseline Sounder

Technical Requirements Document

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National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

NOAA's Technical Requirements for a Geostationary Advanced Baseline Sounder (ABS)

Final Version

1. Requirements Overview

This technical requirements document (TRD) prepared by the National Environmental Satellite, Data, and Information Service (NESDIS) presents detailed requirements for an operational advanced sounding instrument for the GOES platform. The TRD is NOAA's statement of performance characteristics drawn from the National Weather Service (NWS) Operational Requirements Document[1] (ORD), January 1999, from the results of Phase-A instrument concept studies, and from scientific, technical and cost trade analyses. The requirements represent NOAA's advanced baseline for geostationary sounding performance, and thus the notional instrument they define is termed the Advanced Baseline Sounder (ABS).

NOAA is submitting this TRD to NASA for use in generating requests for proposals for the ABS. NOAA assumes that the ABS is distinct from an atmospheric imaging instrument, and spacecraft-specific and ground-processing requirements are excluded wherever possible. However, certain specific performance characteristics described in Section 3, particularly processing of the decimated interferogram, may result in the inclusion of a ground-processing segment as part of the overall "sounder system." The contractors will not be specifying any atmospheric temperature and moisture retrieval algorithms, but will supply needed algorithms for the navigation, for calibration and data compression.

2. Background Information and Design Goals for the ABS

The first ABS will be available for flight in 2010 (threshold) and a goal for GOES-R (launch readiness of 2008). The GOES will be located between 75? West and 135? West. NOAA expects that available technology should be used to design an ABS that at a minimum must meet this document's threshold requirements. NASA through its New Millennium Program (NMP) and its Earth Observing (EO) 3 GIFTS mission is to evaluate and demonstrate new space interferometer technologies. Some of the technologies being evaluated are large format FPAs (Focal Plane Arrays), low-power electronics, data compression hardware and algorithms, and mechanical cryo-cooler. If the technologies are not available for introduction into the ABS for the GOES R launch then possibly through modularity in design they can be introduced into successive units such as for GOES T or U. Critical performance parameters for the ABS are the scanning rate (i.e. spatial coverage), NEdN, and ensquared energy.

In conducting concept studies and technology and risk trade analyses, NOAA has determined several preferred instrument characteristics that are described here as design or engineering requirements:

A. Assumed Sensor Description

NOAA anticipates that the ABS will be a passive imaging infrared Michelson interferometer which measures scene radiance that can be converted into vertical soundings of temperature and humidity through a numerical procedure (known as retrieval analysis) implemented (possibly through ground processing) as part of the sounder system. The sensor is expected to include the following elements:

i. A rigid optical bench suitable for maintaining sensor alignment and pointing knowledge. Vibration isolation provisions, if necessary to maintain instrument performance, should be included to isolate the sensor from the spacecraft.

ii. A scan mirror and servo system which allows the detectors to view the scene, as well as space and a full-aperture calibration blackbody.

iii. A Michelson interferometer, comprising a beamsplitter, moving mirror and servo system suitable for generating interferograms, dynamic alignment mirror and servo system, and metrology system suitable for triggering the sampling of the interferograms.

iv. Fore optics, designed and baffled as necessary to meet the requirements of Section 3.A.1, which couple the radiance from the scene to the Michelson interferometer.

v. Aft optics, cooled as necessary to reduce background radiation reaching the detectors, which relay the interferometer beam to the focal planes.

vi. Cooled detector focal planes, optimized for sensitivity over three anticipated wavebands as detailed in Table 4.

vii. Signal processing electronics which permit the information gathered by the sensor to be downlinked and processed (possibly as part of a ground system) into retrieved temperature and humidity soundings.

NOAA anticipates an aperture size of no less than 30 cm.

B. Spacecraft Interface Design Goals

NOAA maintained a design goal of minimum spacecraft impact while conducting its concept studies. In accordance with this goal, physical spacecraft interface requirements are given here. It is anticipated that the design needs to be compatible with the GOES- R bus. However, NOAA encourages innovative design and recognizes certain proposed instruments may offer trade-offs between performance, cost-effectiveness, and these physical interface parameters. Such trades may cause NOAA to consider redefining this design goal.

a) Mass and Volume: The instrument mass should be no more than the current sounder. To be compatible with the current GOES-N through GOES-Q bus design including all associated electronics and cabling, the ABS volume should occupy no more than the current GOES N-Q volume and the instrument dimensions shall be compatible with the size and location of the instrument slot on the satellite bus.

b) Power Consumption: The instrument should consume no more power in watts than the current GOES N-Q sounder under normal operating conditions.

c) Cooling: Both passive and active cooling can be explored; though passive should be given strong consideration due its greater reliability.

3. Performance Characteristics

Requirements listed in this section result from technical analyses of the National Weather Service ORD, which frames the rationale for most ABS performance characteristics. Additional requirements that are derived from technical concept studies and trade analyses are subsequently listed.

This document employs a two-level definition for most of the requirements:

THRESHOLD: The minimum acceptable capability at end-of-life required at the beginning of the proposed series of satellites. All requirements are threshold unless noted as goals.

GOAL: An enhanced level beyond the THRESHOLD level of performance needed to support future NWS operations. This level of performance should be achieved as quickly as possible during the series of satellites continually infusing advances in technology that improve services with minimal effect on total project costs.

Future Enhancements: Design features which would support modular improvement in moving from any of the THRESHOLDS towards GOALS would be advantageous.

The requirements specified here in the TRD may differ from that in the ORD, reflecting acknowledged technical, scientific or cost factors determined during the ABS Phase A study.

A. Top Priority Requirements

The following two threshold requirements are considered highest priority by the National Weather Service for the sounder:

1. Operation during eclipse and keep out zone periods.

a) The sounder shall be capable of continuous operation during eclipse periods in geostationary orbit.

b) During the daily period of time prior to and following spacecraft eclipse, and during the seasonal periods just prior to and after eclipse when sun light impinges on the sounder optical path (Defined by NOAA as the keep-out-zone period), the ABS shall not acquire data within 3 degrees of the sun nor scan any detector within 1.4 degrees of the center of the sun. Between 3 degrees and 10 degrees of the sun the sounder shall perform as follows:

Emitted IR bands (650 to 1740 cm^{-1}) shall have NEdN thresholds no more than two (2) times values shown in Table 5.

No detectors shall saturate. See also the relating requirement 3.B.11 and the discussion.

Discussion: Geostationary viewing geometry results in sunlight impingement on the optical path of the GOES sounding telescope during the periods of the year several weeks around each equinox. When this happens, stray sunlight may cause a degradation of the radiometric response accuracy of the sounder's Earth-viewing detectors, as well as heating of the telescope. How much degradation and how long this effect lasts will depend on many design features of the sounder. The sounder should be designed in such a way that intrusion of sunlight from outside the field of view is minimized, reducing as much as is practical the need for "keep- out-zones" near local midnight during the equinoxes, and in addition minimize heating of telescope mirrors and mounts. The prohibition of scanning within 1.4 degrees of the sun center is to prevent sounder damage. Focused sunlight on the optics is a cause of potential damage. The energy is sufficient to damage optical materials and coatings, and to irreparably damage detectors. Any detector within 3 degrees of the sun is not required to provide useful data. The relaxation of requirements between 3 and 10 degrees of the sun is done in recognition that stray light will contribute noise in the local midnight condition. A JPL February 2000 report ("Keep-Out Zone Specification for the Advanced Baseline Imager and Background Discussion,") has documented the numbers used in this requirement.

Benefits: Providing near-continuous coverage through the spring and fall eclipse and keep-out-zone periods will give needed IR data during both spring severe weather and fall hurricane seasons.

2. Improve sounder spatial coverage.

The sounder shall produce data (including any time required for on-orbit calibration and star sensing) with the coverage specified below:

a) Scan the region within 62 degrees local zenith angle (although only scan half of the region of over-lap between the eastern and western satellites, nominally at 105W) within one hour (see Figure 1). (THRESHOLD)
b) Scan the full earth disk in one hour. (GOAL)
c) The scan area shall be selectable to offer flexible scan scenarios. This ranges from meso-scale areas (1000 by 1000 km) through the size of the full disk. (THRESHOLD)

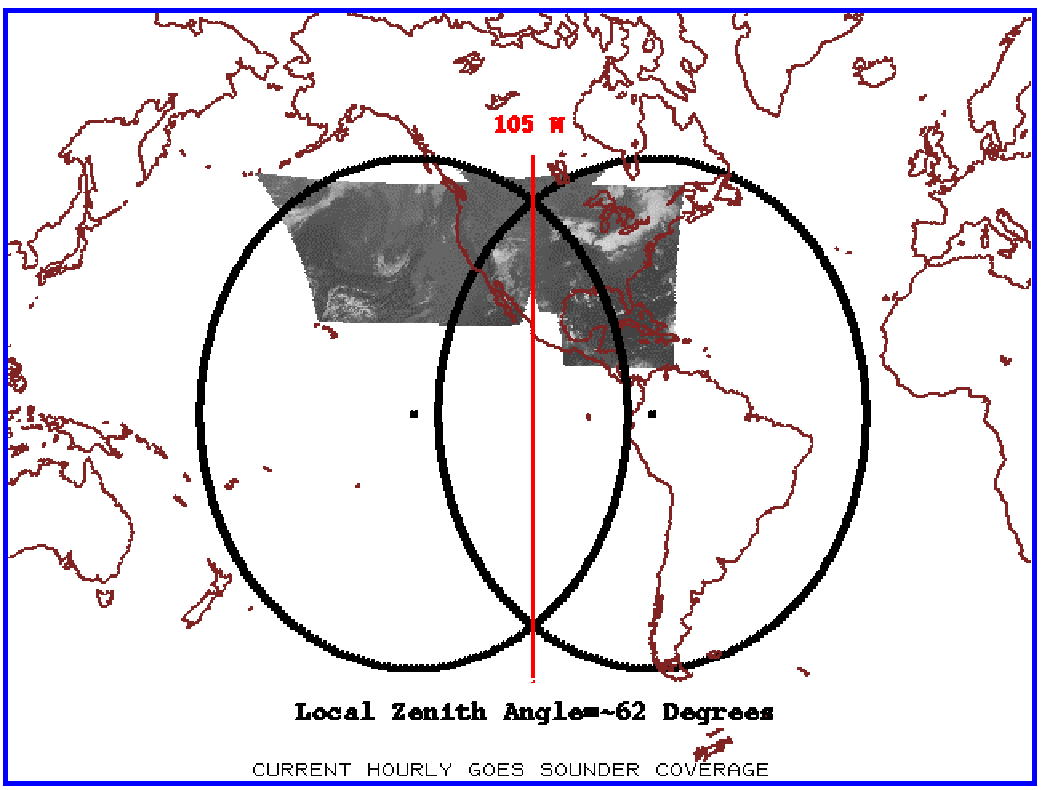

Figure 1. Shown are the approximate arcs of 62 degrees local zenith angle from both the GOES-East and GOES-West sub-satellite points. The threshold coverage rate calls for the region within the 62 degree arc, excluding half of the over-lap region, to the scanned each hour. For information only, an image for one hour of the infrared window

from the current generation instruments are shown.

Discussion: The THRESHOLD requirement does not mean the operational schedule will simply consist of sequential nearly full “sounding” disk images. The CONUS area may be scanned more frequently, allowing more clear observations as clouds move. Southern Hemisphere oceanic regions may be scanned less frequently, which would allow observations over large regions without conventional observations (i.e., the Pacific Ocean).

At this point, NESDIS thinks the full impact of the faster full disk coverage performance goal of one hour on the advanced sounder design and requisite technologies may be a system driver. NESDIS, with NASA, continues to guide engineering studies at FFRDCs (Federally Funded Research and Development Centers) to explore advanced ABS design and concepts directed at faster coverage rates. The threshold scanning requirement is somewhat more than 2½ times faster than the coverage rate of the 5000 x 3000 km per half hour of the base ABS design. This coverage rate represents at least a factor of 5 increase over that of the current filter wheel sounder. The thrust of the NWS sounder scanning needs is to cover both CONUS and large coastal and open ocean areas, particularly in the Pacific. Tropical cyclone coverage is needed as well. The major technology areas to be explored for the increased coverage rate are: increased aperture size, increased number of detectors and focal plane array (FPA) size, greater passive cooling capacity with a lower cooling temperature, and the appropriateness for NOAA of mechanical cooling. Increased coverage rates directly impact NEdN, A/D converter requirements, and data rates.

Current WMO[2] guidance calls for an *optimum* repeat cycle of one hour of sounder coverage for global Numerical Weather Prediction. The faster end of their median range is 2.3 hours.

Over the next decade, national-domain numerical weather prediction (NWP) models will move from an age where many of the physical processes simulated by the models were approximated statistically and the resolution of the forecast models was notably *coarser* than that of geostationary soundings and into an era when most of the physical processes in the models will be treated explicitly and at a resolution *finer* than that of the satellite observations. For example, the Nested Grid Model was implemented in 1986 with a horizontal resolution of 85 km, the current Eta model will be moving from 32 to 10 km horizontal resolution by the end of 2001. This will be approximately nine times finer than the resolution available from the current GOES sounder. By 2010, the resolution of national domain NWP models will approach 2 km and will likely be non-hydrostatic. These models will require higher-space and time-resolution observations and can use these higher-resolution data in new ways (e.g., specifying cloud droplet distributions). Continued improvements in NWP model resolution will occur thereafter, necessitating even higher resolution data as input. (It should be noted that each halving of grid spacing requires over a 10-fold increase in computer power. The expected model resolution improvements are consistent with the increases in computing power predicted by industry during this period.)

The mesoscale data supporting these forecast systems will come primarily from two operational observing systems, doppler radar and geostationary satellites. While the doppler radar will provide 1-2 km resolution precipitation and wind information *after* clouds are already present, the geostationary sounders will be the primary source of localized moisture and temperature (stability) data in clear air *before* the storms develop, as well as information about cloud top structures. These data sets provide natural complements to each other. For example, it has been shown that non-hydrostatic models can do credible jobs of forecasting the short-range evolution of convective systems once they are mature enough to be detected by doppler radar. However, satellite depictions of rapidly changing low-level moisture and stability patterns will be critical in determining the timing and location of the onset of localized convection. Since these two data sets will be used in concert, they must, in the long-term, be of consistent resolution.

Although the initial, minimal "Threshold" requirements for independent 10 km, geostationary moisture and temperature observations are of approximately the same order of magnitude as the expected model resolution in 2010, some features that will be already included in the forecast model at that time may already start to be under-represented in the satellite data. For example, strong low-moisture gradients produced across several kilometers by local variations in antecedent precipitation produced by the model's surface evaporation systems could begin to appear overly smoothed in the 10-km satellite data. Similarly, the structures of clouds being forecast to cover 3 or 4 grid boxes by the model and observed by the GOES imager could be unresolved by the high-spectral resolution sounder.

As model resolution and physical realism continue to increase beyond 2010, the impact of the geostationary sounder data from a "threshold system" will diminish unless the resolution of the observations keeps pace with the increased model resolution and approaches that of the complementary radar data sets. These higher-resolution satellite sounding data will become increasingly critical in improving forecasts of the timing and location of the onset of hazardous weather events ranging from severe convection to localized heavy icing. For example, soundings obtained in the small areas between developing cumulus clouds will be needed to provide a continuous detailed picture of upstream moisture and stability patterns both for forecasting and nowcasting systems, as well as direct forecaster use. To obtain the kinds of observations that assure continued impact of geostationary sounder data beyond 2020, the documented NWS performance "Goals" must be achieved as quickly as possible by assuring an evolutionary observing system improvement path that continually incorporates technological advances which support NWS forecast improvement goals at minimal cost.

Benefits: This spatial coverage rate allows for generation of the satellite radiances and products frequently over the CONUS region for forecasters and regional numerical models, plus allowing greater oceanic coverage for assimilation into global numerical models.

B. Additional Sounder Requirements

Table 1 describes the retrieval accuracy required from the Sounder system for information only, and to tie to the NWS requirements. This TRD ties instrument requirements to these retrieval accuarcies.

Table 1. Sounding Performance Summary: Accuracies and vertical resolution in clear air

Altitude Range	**Observational Accuracy**		**Observational Accuracy**		**Vertical Resolution**	
	Temperature THRESHOLD	**Temperature GOAL**	**Humidity THRESHOLD**	**Humidity GOAL**	**THRESHOLD**	**GOAL**
Surface – 300 hPa	? 1.0 K	? 0.5 K	? 10%	? 5%	**Surface – 500 hPa**; 0.3 – 0.5 km layers **500 – 300 hPa** 1 – 2 km layers	**Surface – 500 hPa**; < 0.3 – 0.5 km layers, **500 – 300 hPa**; < 1 – 2 km layers
300 hPa – 100 hPa	? 1.0 K	? 0.5 K	? 20%	? 10%	1 – 2 km layers	< 1 – 2 km layers
100 hPa and above	? 1.0 K	? 0.5 K	N/A	N/A	2 – 3 km layers	< 2 – 3 km layers

The IR bands shall have 10-km ground sample distance in both directions. The visible band shall have 1-km ground sample distance in both directions. The contractor must develop and demonstrate an algorithm capable of verifying all instrument parameters at the output of any ground-processing running at rates comparable with scanning rates.

Discussion: During Phase-A concept design and technology studies, it was determined that meeting an 80% ensquared energy requirement would entail an aperture diameter of at least 25 cm, and that further improvement in ensquared energy (>90%) would be gained by additional measures such as decreasing the detector fill-factor to optically isolate abutting FOV's, and/or spatially filtering (apodizing) the pupil to mitigate diffraction effects. The threshold requirement is for 10 km x 10 km field-of-view with 90% ensquared energy. The goal is for 2 km x 2 km field-of-view with 95% ensquared energy.

Benefits: Increasing the spatial resolution greatly increases the likelihood of obtaining clear-air soundings, and improves the ability of ABS to obtain soundings adjacent to cloudy regions.

Table 2. ABS Observational Requirements Summary (Partial List)

Requirement and Source		Threshold
Spatial resolution[1,3]	Visible	1 km IFOV to enable Accurate cloud-cover detection
	IR	10 km (280 ?rad) square
Ensquared energy (all bands)[4]		At least 90% of the response detected in a sample must originate from a 10x10 km ground sample corresponding to this FOV (see 3.B.2)
Spatial coverage rate	The region within 62 degrees local zenith angle (except only half of the over-lap region between two satellites) (**Figure 1**)	Each hour, including any necessary allowance for IR calibration and star sensing Operational scenarios may deviate from scanning the arc every hour, but this coverage rate is needed to provide both CONUS and a minimum adequate level of ocean coverage
	Regional and Mesoscale when required	Must be supported and selectable
Visible imaging star sensing		4 stars per half hour
Operation during eclipse[1]		Yes
Timeliness of data[1]	Radiance	3 minutes
Simultaneity[1]		Within 10 sec. for all bands at any FOV (Limits cloud encroachment in FOV to < 10%)
IR Spectral bands and spectral resolution **Radiometric Sensitivity** **Dynamic Range**[3,4]		(**Table 3**)
Navigation (Vis and IR)[1]		? 2.5 km (? 70 ?rad) at SSP
Registration within frame[1]		? 2.0 km (? 56 ?rad) at SSP
IR band linearity		See 3.B.2.j
Registration image to image	Visible IR[1]	? 2.5 km (? 70 ?rad) in 30 min. ? 2.5 km (? 70 ?rad) in 30 min.
Band to band co-registration	Visible-IR	? 1.0 km (? 28 ?rad)
	IR-IR[1]	? 1.0 km (? 28 ?rad) (< 10% of FOV)
On-orbit calibration	Visible	Signal-to-Noise of 300:1
	IR	See 3.B.13

Table 2 (Continued). ABS Observational Requirements Summary

Data rate		10 Megabits-per second (Mbps)
Lifetime[6]	Ground storage	2 years
	On-orbit storage	3 years
	Mean Mission life	8.4 years
	Design life	10 years

1. Lifetime

The instrument shall be designed to meet all specifications during a GOES mean mission duration of 7 years, with 2 primary sensors, which may follow up to two years of ground storage in a controlled environment and three years of on-orbit storage. ABS design life should be 10 years, Mean Mission Duration (MMD) 8.4 years, and reliability at design life of 0.6. An extended 7-year lifetime is a NOAA priority for the GOES and ABS program (THRESHOLD).

> *Discussion:*[6,7] NESDIS studied the benefits of extending the 5 year present lifetime of the current GOES series to 7 years, as well as issues associated with extending the lifetime as a way to contain and reduce program costs. Given NOAA had to introduce new sensors to meet NWS requirements as well as provide replacements and new designs because of the need for competition, it was timely to look at the longer life. Major long lifetime issues would be: Avoiding single point failure designs, long life evaluation through accelerated lifetime testing of selected components such as mechanisms, thermal control of optics and electronics, analyses such as FMECA (Failure Mode, Effects and Criticality Analysis).
>
> *Benefits:* Extending the lifetime from the present 5 years to 7 years, a 40% increase, will save NOAA money by reducing program costs. It will over a 15-year period reduce the number of satellites needed by two. Present costs for GOES launches, spacecraft bus, and sensors are approximately $250 Million. NOAA expects the extended life savings will pay for the new ABI and ABS sensors over a 15-year period, and if the new designs continue beyond 15 years, savings will continue to accrue.

2. Types of observations and accuracies

The sounder must yield spectral radiance observations suitable for retrieval of temperature and relative humidity over a three-dimensional set of reporting intervals defined below. The vertical observations shall be retrieved from measured radiances over a two-dimensional grid defined as horizontal cells.

> a) Soundings-- these refer to retrieved profiles of atmospheric temperature and humidity as defined below. Note that it is not the intention of this document to specify sounding algorithms, but rather to specify radiometric performance determined in Phase-A studies to be sufficient to meet the observational requirements of Table 5.

b) Atmospheric Temperature Profile – this consists of a set of estimates of the average atmospheric temperature in a three-dimensional volume (cell) centered on a specified point on a vertical line extending above a fixed longitude and latitude. The observational accuracy requirements given in Table 1 represent errors in a given layer.

c) Atmospheric Humidity Profile – this consists of a set of estimates of the average mixing ratio in a three-dimensional volume (cell) centered on a specified point on a vertical line extending above a fixed longitude and latitude. The observational accuracy requirements given in Table 1 represent errors in a given layer.

d) Spatial Sampling – this corresponds to the 2-dimensional horizontal ground sampling distance in km at nadir.

The THRESHOLD spatial sampling of the IR bands shall be 10 km, and 1 km for the visible band measured at the satellite sub-point (SSP). The GOAL spatial resolution should be 2 km for the IR bands at the SSP and 0.5 km for the visible band.

Discussion: This spatial resolution corresponds approximately to that of the GOES I-O sounders, and is the minimum acceptable spatial resolution of the ABS. Because the sounding retrieval process is corrupted by the presence of cloud cover over even a portion of an IFOV (due to the high contrast in brightness temperature between clear and cloudy air), it is necessary to further refine the requirement for spatial resolution by specifying the ensquared energy.

e) Ensquared Energy – this is a unitless figure of merit which is the ratio of the energy reaching a pixel from its corresponding 10 x 10-km sample to the energy reaching this pixel from the entire scene. It provides a measure of the rejection of out-of-field energy, addressing the diffraction spreading effects and focal plane crosstalk issues from adjacent detector samples.

This quantity is defined in terms of the scene spread function, which is the convolution of the polychromatic system point-spread function (PSF) at the detector focal plane with the detector pixel geometry and signal spreading. Upon projecting (geometrically) this quantity to the earth scene, the relative response of the system as a function of location is obtained. The ensquared energy is given by integrating the scene spread function spatial response over the horizontal sounding cell area (the energy measured from the area to be sounded) divided by the spatial response integrated over *all* the area (the total energy measured).

The THRESHOLD ensquared energy shall be greater than or equal to 90% in the 10 km sounding cell (THRESHOLD). The GOAL ensquared energy is 95%.

Discussion: The retrieval of soundings through "holes" in cloud cover, and near the edge of cloud-covered regions, is corrupted by crosstalk between samples which causes cloud contamination to affect nominally cloud-free FOV's. It is expected that ABS may be less susceptible to these effects than the GOES I-O sounder if measures are implemented such as reducing the detector fill-factor to optically isolate the FOV's, and/or by spatially tapering ("apodizing") the pupil illumination to reduce optical crosstalk arising from diffraction effects.

f) Horizontal Cell Size – this is a measure of the area (assumed to be square) which corresponds to a retrieved sounding. In the absence of cloud cover, the horizontal cell size may correspond to the IFOV. When cloud cover is present, necessitating a sampling of several IFOV's to obtain a cloud-free sounding, or when averaging of several cells is used to reduce NEdN, the cell size may correspond to several IFOV's.

As a THRESHOLD the horizontal cell size shall be 10 x 10-km, measured at the SSP. As a GOAL the horizontal cell size shall be 2 x 2-km at the SSP.

g) Sensing Wavebands – these refer to the spectral regions in which observations are obtained which are subsequently processed to retrieve profiles.

The sounder shall sense radiance according to the following table of bands, defined by minimum and maximum wavelength frequency, and spectral resolution. All values are THRESHOLD requirements.

Table 3. Sounder Waveband Descriptions

Waveband (cm^{-1})	**Unapodized spectral resolution (cm^{-1})**	**Number of bins (**1532**)**
650 – 1200	0.625	880
1210 – 1740	1.25	424
2150 - 2720	2.5	228

Discussion: Based on studies performed at MIT/LL, and at CIMSS (Cooperative Institute for Meteorological Satellite Studies), these wavebands have been selected based on their utility in producing the desired sounding retrievals. In developing the wave band requirement, the smallest wavenumber (longest wavelength) band was extended from 650-1150 to 650-1200 to include information near 8.5 µm. MIT-LL has done phase A studies for NOAA investigating how to reduce the variation in radiance reflectance that occurs at varying scan angles at certain wavelengths near 8 microns with SiOx mirror coatings used on the current GOES I-M imager and sounder instruments.

h) Detailed Discussion of Wavebands – there is no unique set of wavenumbers for an interferometer. The radiance spectrum obtained from the cosine transform of the sampled interferogram is continuous and well defined at all wavenumbers in the band.

Number of wavenumber channels: A fast Fourier transform (FFT) of a sampled interferogram provides a set of spectral radiances uniformly spaced by the wavenumber step size across the band. The spectral response at any wavenumber in the band may be obtained by interpolating between these wavenumber values.

Aliasing: The interferometeric signal shall be appropriately sampled to minimize noise aliasing and moving mirror velocity fluctuation errors.

Wavenumber step size: The wavenumber step size (d?) between spectral data points is defined as the reciprocal of the optical path difference (OPD) between the first and last samples of the sampled interferogram. The wavenumber step size will vary with off-axis field angle and each detector FOV must be appropriately compensated.

Unapodized spectral resolution: The unapodized spectral resolution is defined as the reciprocal of twice the maximum optical path difference from zero path difference (ZPD), i.e. if the maximum OPD change is L, the wavenumber step size is $1/2L$.

Retrieval spectral channel wavenumbers: The on-axis set of nominal retrieval spectral channel wavenumbers shall be provided.

i) Dynamic Range – The dynamic range for each band shall be sufficient to span the range from the brightness temperature corresponding to the space background to the temperature of the blackbody calibration target, or the highest scene temperature (whichever is larger).

j) System Linearity – the nonlinearity of specific spectral bands across the instruments' dynamic range shall be measured and demonstrated to be stable enough to meet all radiometric requirements. This implies a threshold of less than 1% and a goal of 0.2%.

k) Quantization – The bands shall be quantized in such a way that the signal will not saturate (high counts or low counts) over the life of the instrument and under worst case conditions. The quantization noise should not be the dominant noise source.

l) Noise-Equivalent Temperature Difference (NEDT) and Noise-Equivalent Radiance Difference (NEdN) – The noise performance requirements are defined at the aperture of the system by the noise-equivalent radiance difference (NEdN) arriving from the top of the atmosphere (TOA). The NEDT at a given wavenumber is defined by dividing the NEdN at that wavenumber by the derivative with respect to temperature of the Planck blackbody radiance function, evaluated at 300 K at the same number.

m) Earth Scene Variation – The noise performance of the instrument will depend on the earth scene. The earth scenes plotted in Figures 2 through 4 are representative of the extremes in earth radiance. The interferometer noise will depend on the broad band integrated flux. The blackbody temperatures for equivalent in-band scenes' radiance are given in Table 4. The radiance levels from blackbodies of these temperatures are plotted in Figures 2 through 4 along with the earth scene radiances which they simulate.

Table 4. Blackbody temperatures for equivalent in-band scene radiances.

	Hot (K)	Nominal (K)	Cool (K)
Band 1: 650 – 1200 cm^{-1}	289	267	233
Band 2: 1210 – 1740 cm^{-1}	267	251	234
Band 3: 2150 – 2720 cm^{-1}	287	269	233

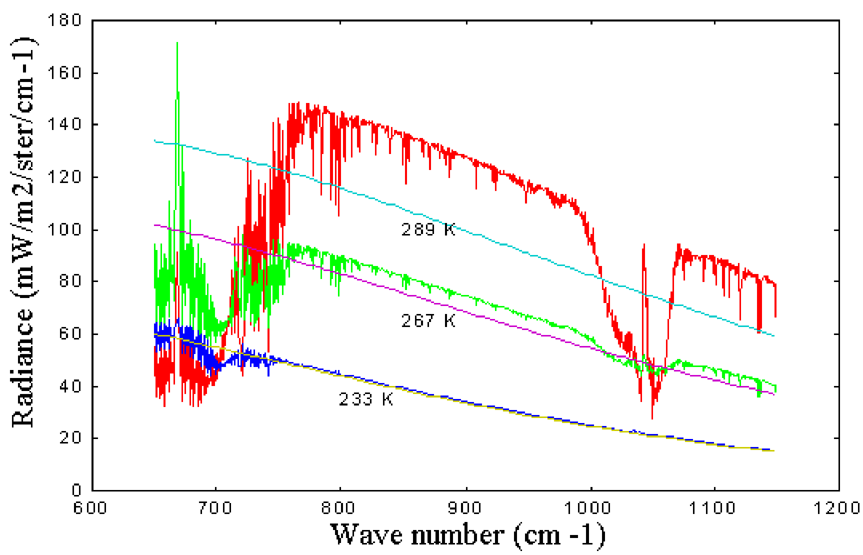

Figure 2. Three earth radiance profiles for the LWIR band (Band 1)

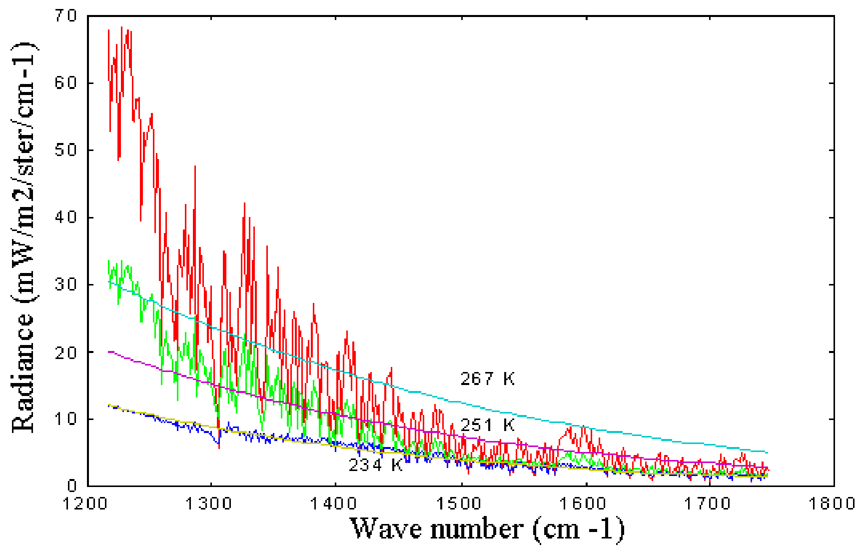

Figure 3. Three earth radiance profiles for the MWIR band (Band 2)

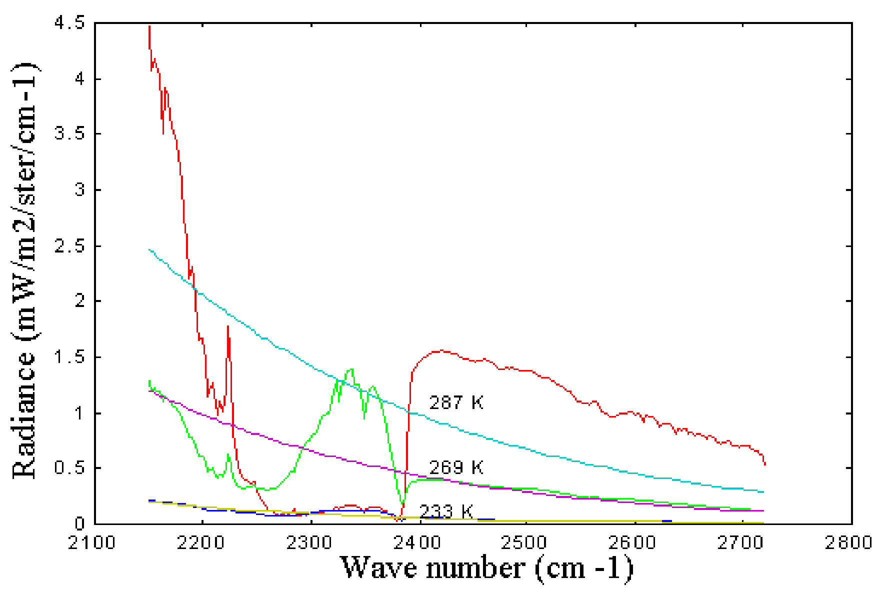

Figure 4. Three earth radiance profiles for the SWIR band (Band 3)

From Figures 2 through 4, blackbody temperatures of 233 K and 289 K are sufficient to produce integrated flux levels representative of the highest and lowest integrated flux expected for the ABS sensor on-orbit.

n) Noise Radiance Performance – The ABS shall be designed to provide data to meet the observational accuracy requirements in Table 1, and as such shall meet the performance in Table 5. The maximum allowed radiance NEdN values sufficient to meet these observational requirements, as determined in Phase-A studies, are tabulated in Table 5. These values reflect the need to have similar noise characterizes from the polar-orbiting systems (i.e., CrIS) and the geostationary sounders to obtain the needed retrieval performance in Table 1.

Table 5. Maximum allowed NEdN at a Test Target Temperature of 289 K

Wavenumber range (cm^{-1})	**Bin size (cm^{-1})**	**Max. NEdN [mW/(m^2 sr cm^{-1})]**
650 – 670	0.625	1.0
670 – 685	0.625	0.7
685 – 700	0.625	0.5
700 – 1150	0.625	0.15
1150 – 1200	0.625	0.30
1210 – 1740	1.25	0.06
2150 – 2720	2.50	0.008

The system should be flexible to allow increasing the effective dwell time to increase the signal-to-noise ratio for selected scans.

3. Sounder System navigation

(Earth location) errors shall not exceed 2.5 km (3-sigma) as THRESHOLD. The goal is to improve the navigation accuarcies to better than 1.0 km. Image navigation refers to the precision to which the longitude and latitude of each pixel within an image can be determined. The determination of location and registration will be via the centroid of the spatial response of the pixel.

The overall "sounder system" may include appropriate real-time ground processing of data. Also see sections: Data Timeliness (3.B.8), Ground Processing (3.C.1) and Spatial Sampling (3.C.2).

If the goal of a finer spatial resolution is realized, then comparable improvements in navigation are needed.

Benefits: All quantitative radiances and products from the sounder require accurate earth-located satellite data.

4. Data format

The data format must allow integration of sounder data with other NWS data sources. To facilitate data use and integration, the final calibrated, navigated ABS data shall be distributed as radiance spectra (THRESHOLD).

> *Discussion:* While a 'fixed grid' projection makes sense for the ABI system, due to the non-linear nature and use of the sounder data, the native format is preferred.
>
> *Benefits:* In addition to users of the spectra for meteorological applications, this will allow a host of new users in diverse fields of chemistry and land processes.

5. Co-registration and scene spread function matching

a) Centroid co-registration errors between sounder bands shall not exceed 10% of the narrowest scene spread functions (THRESHOLD).

b) The visible-IR co-registration shall be within 1 km. (THRESHOLD)

c) The shape of each scenes spread function shall be uniform within TBD% of the scene spread function. It is expected that this will be on the order of 10%.

> *Benefits:* Since the sounding process involves the combination of data from each of the individual spectral regions, it is vital that each of the spectral regions view as closely as possible the same area of the earth nearly simultaneously. This becomes especially important in regions of strong gradients.

6. Pixel-to-pixel registration within frame

Within an image, any adjacent observations shall be known to be within 1.0 km. The distance between any two samples shall be known to within 2.0 km. (THRESHOLD). The goal is for it to be know to better than 1.0 km.

> *Discussion:* These requirements are intended to define the limits of acceptable within-image distortions. There will be sounder products based and displayed for each pixel location.
>
> *Benefits:* Since a major use of the sounding data will be in providing information contained in the gradients of the observations, the relative locations are critical.

7. Jitter

The requirements for jitter are defined in two ways: motion of a pixel relative to a fixed grid during acquisition of an interferogram (staring jitter) and motion of a pixel between soundings (frame-to-frame registration).

a) *Staring jitter*: The line-of-sight of any band shall remain stable to within **TBD** ?rad during the dwell time required to obtain an interferogram.

   Discussion: Scene jitter during the time in which an interferogram is obtained produces spurious modulation at the detectors, which introduces error, the significance of which is dependent on the nature of the scene. The staring jitter value shall be less than 10% of an IR FOV.

b) *Frame-to-frame registration*: The frame-to-frame (up to 30 min) registration error shall be 2.5 km (as measured at nadir) or less between any two consecutive soundings (3-sigma) (THRESHOLD).

Discussion: Frame-to-frame registration refers to the precision to which the position of each pixel within a frame can be determined relative to some reference point. For registration between frames, this reference is drawn between the same pixel in subsequent frames.

Benefits: Reducing the jitter will lead to improved soundings. Improving the frame-to-frame registration is important when viewing loops of either the radiance fields or those of derived products.

8. Data timeliness

Calibrated, earth-located, co-registered (band-to-band) observed radiance data must be available in their entirety at the NOAA CDA (Command Data and Acquisition) ground station within three minutes from the time the scanning of the area is complete (THRESHOLD). The goal is to improve the data timeliness to less than 30 seconds. The maximum allowable delay will be 5 minutes after scanning for any pixel.

Benefits: Making the radiance data (and derived products) available sooner will increase its value to both forecasters and numerical models.

9. Data simultaneity

Data from all sounder bands obtained for any specific point on Earth must be coincident within 10 seconds (THRESHOLD).

The dominant direction of instrument "scan" must be in the East-West directions. To accommodate a seasonal Yaw flip (similar to that on the GOES-10 spacecraft), stepping must be possible in both North to South and South to North directions. See Section (3.B.13) concerning scan effects on calibration.

Discussion: This requirement is needed to ensure accurate generation of soundings which depend on data from all spectral bands. In particular, this requirement is imposed to ensure that cloud encroachment into the FOV is less than 10% during data acquisition.

Benefits: Minimizes uncertainty due to cloud contamination and solar heating.

10. Recovery time

The sounder shall be capable of full operations within 1 hour following spacecraft maneuvers (THRESHOLD; GOAL is 5 minutes).

Discussion: Routine operations should not be re-established too quickly to endanger the health or safety of the instrument.

Benefits: Excessive delays in resuming routine sounding operations following mandatory outages associated with maneuvers can threaten continuity of weather surveillance and result in degradation of forecasts of severe weather.

11. Degradation of performance around spacecraft local midnight

Degradation of performance or outages around spacecraft local midnight must be minimized:

a) any (thermal IR) radiometric degradation reducing data quality to below specification, resulting from sunlight impingement on sounder optics, must be limited to when the sun is within 10 degrees of the sounder optical line of sight (THRESHOLD).

b) any sounder outages needed to ensure health and safety of the instrument when sunlight may enter the instrument optics must be limited to when the sun is within 3 degrees of the optical line of sight (THRESHOLD).

Discussion: See Section 3.A.1. NOAA would like to encourage thorough analysis and innovative designs to minimize this “keep-out-zone” phenomenon.

Benefits: If the “keep-out-zone” phenomenon is minimized, both more and higher quality data can be observed.

12. Visible calibration

The visible calibration should be stable and compared to a NIST reference pre-launch.

13. Infrared Calibration

On board (full aperture) calibration must be provided to achieve brightness temperature Absolute accuracy of ± 1.0 K (THRESHOLD) for each band and traceable to a NIST standard. (The absolute accuracy requirement means that if the true value for a band is X K, then the calculated values must be between X minus 1 and X plus 1 K.) A cold reference may be provided by a space look. The relative accuracy (precision) of each band shall be ± 0.1 K (1-sigma) for the following categories of relative error: a) Line to line, b) Detector to detector, c) channel to channel, d) calibration to calibration. Optical and structural elements that influence the radiometric response of the instrument to the calibration blackbody shall be temperature monitored to 0.1 K precision and telemetered for data correction by ground processing.

Discussion: The calibration standards employed for on-orbit calibration of ABS shall provide sufficiently accurate radiometric temperature to enable ABS to meet the observational accuracy requirements listed in Table 5 (and implicitly Table 1) with instrument parameters in Table 2 and in Section 3.B.2 at THRESHOLD values.

It is assumed that the value of the IR absolute calibration will not vary widely between adjacent radiance bins.

Radiometric accuracy of the ABS system should be independent of scan position (or location of the target in the field of regard). All calibration tolerances are 3-sigma.

Benefits: All soundings and products rely on accurate calibration.

14. Contemporaneous visible imaging capability

Contemporaneous and collocated visible data are required with the sounder IR data. The spectral range is approximately 0.52 to 0.7 µm. The signal to noise shall be 300:1 at the 100% albedo level. The resolution shall be 1.0 km with 0.5 km as a goal.

Discussion: A serious handicap to producing accurate infrared only sounding retrievals is the difficulty of dealing with cloud contamination. Experience has shown that visible data are of great benefit during daylight hours for identifying cloud-free FOVs, especially the higher resolution visible data (sub-IR pixel size). Perhaps more importantly, however, high resolution visible data may allow for correcting IR radiances for subpixel cloud contamination, permitting retrievals of clear air sounding and cloud information in more of the meteorologically active areas. High-resolution sounders such as the ABS can anticipate frequent cloud contamination near storm systems so that sounding will improve with contemporaneous and collocated high-resolution visible data.

15. Low-light Visible capability

The goal for the sounder's visible imagery is that it should be made available even in low-light situations.

Discussion: Due to the increased dwell times compared to an imager, the sounder visible data may be more sensitive in low-light regions.

Benefits: Better depiction of near nighttime fog and thunderstorms. This may also improve knowledge of the location of the center of tropical disturbances.

16. Visible Imaging for Star Sensing

Visible imaging shall be available to map stars to improve navigation. Such star mapping shall permit four (4) stars to be observed per half-hour.

17. Ground Processing Needs

In order to minimize raw data rates which must be downlinked, NOAA recognizes that some of the processing of sensed data (e.g., Fourier-transformation of decimated interferogram data) may be best accomplished on the ground before the final calibrated, navigated ABS data is distributed.

Where the sounder design requires that ground processing of data is done in order to meet certain data specifications (e.g., co-registration, MTF matching across IR channels, navigation accuracies), then such processing must be included in the overall "sounder system design." NOAA recognizes that some optical designs may be simplified or allow for delivery of better quality data meeting defined sounding quality specifications if certain aspects of data processing are performed with ground equipment. Any ground processing aspects of the "sounder system" must still allow the stated timeliness requirements to be met.

18. Limits to Downlink Data Rates

NOAA assumes that the GOES spacecraft communications sub-system will serve to relay ABS data to NOAA ground receive systems in real time. Data rate limits must be placed on ABS performance to assure valuable limited available bandwidth is not inefficiently used, nor unnecessary burdens placed on spacecraft design and cost. Also we need to be assured the data rate capability of the spacecraft links can handle the ABS and other spacecraft needs. The ABS data rate, whether the threshold coverage rate (Figure 1) or full disk coverage rate both at 10 km resolution, shall be no more than 10 Mbps. This number is based on data from a number of companies doing concept studies on the likely data rates along with the reality of a limited L-band data rate capability. This value allows a nominal 19 Mbps for the ABI, 10 Mbps for the ABS, and 1 Mbps for what is now designated the multi-use Data Link (MDL) which would contain the data rate for the instrument of opportunity. ABI, ABS, and MDL will be integrated into one data stream. This limit was set using the least capable communication design option. Other available options rely on different technologies and have more capability. Our desire is to keep open at this time the various options until the major technology and cost issues have been fully explored. As the ABS and ABI designs as well as the communications design become more complete, this maximum data rate may be revised.

Discusion: The ABS data rate limit was set using the most recent staff analyses that showed threshold (Figure 1) and full disk coverage rate requirements with 10 km IR spatial resolution were in the range of 7 and 10 Mbps. We recognize that finer resolution such as that provided by GIFTS and the 2 km IR goal resolution of the NWS will generate a higher data rate. We are not sure at this point about the feasibility with available technology of having an ABS with a coverage rate faster than the goal and a spatial resolution finer than 10 km. If it is feasible we may then have to raise the limit. The ABI may not require all of the 19 Mbps data rate limit allocated for its performance. NOAA's concept studies on communication downlink options are at an advanced stage but still being refined. These communication studies should be by the spring of 2001 at a point that we can know with more confidence the data rate limits, costs, and technology risks with the communication options. We may after that time be able with that information to further increase the ABS allocated data rate limits.

19. Data compression acceptability

NOAA recognizes that in order to meet both timeliness requirements and downlink data bandwidth limitations, some form of data compression may need to be invoked. Compression of data, should it be necessary, may be carried out by any means (e.g., Huffman coding, arithmetic coding, Rice algorithm) which permit lossless reconstruction of the data (GOAL). If this goal can not be attained, then some lossy compression will be allowed. The allowable compression amount is TBD, but would be limited to the amount which would allow a retrieval to be generated with similar accuracy (compared to that from the lossless compression).

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[1] NWS Operational Requirements for Future Geostationary Operational Environmental Satellites, J. J. Kelly, 8 January, 1999

[2] WMO/ TECHNICAL DOCUMENT No. 992, 2000: Statement of guidance regarding how well satellite capabilities meet WMO user requirements in several application areas, Appendix B – Global NWP.

[3] Based on Phase A studies at MIT/LL

[4] P. Menzel, NESDIS

[5] NASA, "Interface Control Document for the Geostationary Operational Environmental Satellite GOES NOPQ Sounder", Table 3.2.1-1, Document number 8175751A, 14 August 1997, ABS mass

should be no more than that of the current ITT sounder. Power and volume should be no more than current ITT sounder.

[6] R.W.Dezelan “Mission Sensor Reliability for Advanced GOES Spacecraft”, The Aerospace Corp, Project Report ATR-2000(2331)-2, 23 December 1999

[7] JPL report "Study Report on a 30cm Aperture Advanced Imager for GOES , Vol 11: Designing for a Long Life", JPL Document No. D-16414, November 1998